NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

April 11, 2006

MATERIALS LABORATORY FACTUAL REPORT Report No. 06-021

A. ACCIDENT

Place	:	Lake George, New York
Date	:	October 2, 2005
Vehicle	:	Small passenger vessel “Ethan Allen”
NTSB No.	:	DCA06MM001
Investigator	:	Brian Curtis

B. COMPONENTS EXAMINED

1. Raw water pump from the Ethan Allen.
2. Exemplar raw water pump tested at Cummins Diesel.
3. Previous raw water pump.

C. DETAILS OF THE EXAMINATION

The raw water pump removed from the engine, after the vessel had been recovered, is illustrated in figure 1 with major components identified and the forward (FWD) direction, as installed on the engine, indicated. The identification tag indicated in figure 1 displayed the manufacturers name, “SHERWOOD”, the pump part number, “M71-01-90” and the pump serial number, “05132”. The tag also displayed “Division of Hypro Corporation” and the telephone number “651-766-6300”. The exemplar pump had been utilized for the testing performed at Cummins Diesel and had been retained for comparative examination. The exemplar pump is illustrated in figure 12 and displayed an identification tag, similar to that on the accident pump, but with the part number “M71-01” and the serial number “05301”. The previous raw water pump from the Ethan Allen was retained, found to be incomplete and is illustrated in figure 15. The accident pump reportedly replaced the previous raw water pump in July 2005.

The raw water pump provides cooling water to the engine and is normally located at the forward end of the engine on the left side. The engine drives a gear, which is part of the pump assembly. The gear in turn drives a shaft that passes through the pump’s bearing housing and into the pump housing. The bearing housing contains bearings and seals that support the shaft and prevent leakage of water, from the pump side, or oil, from the engine side (drip holes are located between the bearings and seal assemblies to

provide an indication of seal failure). The wear plate provides a sealing (and wearable) surface for one side of the impeller and is installed between the bearing housing and the pump housing. The impeller, located in the pump housing, is keyed to the shaft and is made of an elastomeric material, with twelve lobes, on a metal core. Pumping action is achieved as the impeller lobes pass over a cam located in the pump housing. The cam reduces the volume between the lobes, forcing the water out of the pump and into the engine cooling system.

Accident pump examination.

The accident pump is illustrated in figure 2 still installed on the engine after the recovery of the vessel. The major components are identified as in figure 1 with the green arrows indicating the direction of water flow through the pump. The blue arrow indicates the lower adapter plate bolt that was found loose, as illustrated. For identification purposes the three bolts securing the pump housing to the bearing housing were identified with a clock position when looking from the front of the engine. The housing bolts are identified as 3:00 (for 3 o'clock), 7:00 (for 7 o'clock) and 11:00 (for 11 o'clock) as illustrated in figure 2 (the identification is repeated in figure 1). The on-scene examination revealed the presence of a gap between the pump housing and the wear plate. The gap, indicated by the red arrow in figure 2, was measured at 0.076 inch at that location, adjacent to the 7:00 housing bolt. During subsequent pump removal and handling the gap had been almost closed, as indicated by the red arrow in figure 1, and produced the gap illustrated under the heads of the housing bolts.

The housing bolts are inserted through holes in the bearing housing, through holes in the wear plate, and screwed into matching threads in the pump housing. Lock washers are installed between the bolt head and the bearing housing. The three bolted attachments are illustrated and identified in the three views of figure 3 with an insert view of the bolt, at a similar scale, after it had been removed. Examination of the bolts, as installed, revealed that the gap between them and the bearing housing was sufficient to allow the lock washer to rotate freely. The examination also revealed that the 3:00 and the 7:00 bolts did not penetrate through the thread in the pump housing whereas the 11:00 bolt did penetrate slightly, as indicated by the red arrow in the right view of figure 3.

The housing bolts were removed for examination. The threads displayed the onset of corrosion, indicated by the yellow arrows in the inserts of figure 3. The corrosion appeared to start at the location of the wear plate, as indicated by the red line in each insert view, and continued towards the head of the respective bolt. The 3:00 bolt displayed corrosion that encompassed approximately two threads, the 7:00 bolt displayed corrosion that encompassed approximately 3 threads and the 11:00 bolt displayed corrosion that encompassed approximately one thread. The flanks of the threads did not display any distinct smearing normally associated with the bolt being torque loaded.

The examination of the housing bolts also revealed that plating had been removed from the underside of the head, on the shouldered face normally in contact with the lock washer. The undersides of the housing bolt heads are illustrated and identified in figure 4

with the areas devoid of plating indicated by the yellow arrows. The red arrow on the contact face of the 7:00 bolt indicates a circumferentially oriented smearing of the remaining plated surface.

Lock washers of the type utilized with the housing bolts are commonly referred to as helical spring lock washers. When a helical spring lock washer is compressed during a bolt tightening operation, the contacting faces slide over each other. When the bolt is loosened the sharp edge of the lock washer digs into the contacting faces to leave a distinct impression that displays the orientation of the sharp edge. With softer materials, the sharp edge of the lock washer can dig a trough and displace material forward to leave a distinctly straight roll of material on those faces. To determine if this would occur with the housing bolts and lock washers, a test was performed after completion of the examination. Exemplar bolts and lock washers, supplied by the pump manufacturer, were individually assembled and torque loaded to 5 foot-pounds and 8 foot-pounds (the lower and upper limits specified by the pump manufacturer), then loosened. The left view of figure 5 illustrates the contact faces of two exemplar bolts that were torque loaded at 5 foot-pounds and 8 foot-pounds using a steel nut as a substitute for the threads in the pump housing. The yellow arrow indicates a small roll of material barely visible on the contact face of the bolt loaded at 5 foot-pounds and the red arrow indicates a distinct roll of material on the contact face of the bolt loaded at 8 foot-pounds. The test was repeated using a brass thread (one of the pump housing threads). The results are illustrated in the right view of figure 5 where the red arrows indicate distinct rolls of material on the contact faces of both bolts. Material deformation similar to that created on the exemplar bolts was not found on any of the three bolts from the accident pump.

The lock washer contact faces on the bearing housing were then examined. The lock washer for the 3:00 bolt was in contact with the identification tag, as illustrated in figures 1, 2 and in the left view of figure 3. Examination of the contact face on the identification tag revealed the distinct surface indentation indicated by the yellow arrow in the left view of figure 6 and the circumferential smearing indicated by the red arrow. The indentation displayed the trough and roll features consistent with the loosening of a bolt and lock washer previously described. The angular location of the impression matched the angular location of the edge of the lock washer. Manipulation of the tag suggested that it had been manufactured from a very soft aluminum. The contact face around the hole in the bearing housing displayed the slight flattening of isolated locations on the dimpled surface, indicated by the red arrows in the right view of figure 6. The blue arrow in the right view indicates a shallow straight-line feature that displayed rounded contours and was at the wrong orientation to have been produced by a helical spring lock washer.

The lock washer for the 7:00 bolt would normally be in contact with the bearing housing surface illustrated in the left view of figure 7. The yellow arrow indicates a distinctive straight indentation, with material forced forward in the direction indicated by the arrow, which could be produced by the loosening off of a helical spring lock washer. The red arrows indicate a slight flattening of isolated locations on the dimpled surface.

The spring washer for the 11:00 bolt would normally be in contact with the bearing housing surface illustrated in the right view of figure 7. No distinctive indentation was observed, and the red arrows indicate a slight flattening of isolated locations on the dimpled surface.

The removal of the housing bolts allowed the pump housing to be removed and examined. The examination revealed that the flanks of the threads in the pump housing did not display any distinct smearing normally associated with the bolts being torque loaded.

The partially disassembled pump is illustrated in the left view of figure 8 with the major components identified. The impeller is illustrated in the pump housing and has five of its lobes in contact with the cam, illustrating the pumping action previously described. The black arrow on the wear plate indicates the profile of the cam. The white arrow on the pump housing indicates the o-ring that seals the housing to the wear plate, and the blue arrow indicates a well defined imprint of the o-ring on the wear plate, indicative of a good all-round contact. The o-ring was removed from the pump housing and was found to have retained its round cross-section. The yellow arrow indicates the discolored surface of the wear plate, normally contacted by the side of the impeller illustrated in the pump housing. A closer view of the discolored surface on the wear plate is illustrated in the right view of figure 8 with a yellow arrow indicating one of the numerous imprints of an impeller lobe. The blue arrow indicates the o-ring imprint indicated by the blue arrow in the right view.

The wear plate was removed to reveal a gasket between it and the bearing housing. The gasket remained on the bearing housing and is illustrated and identified in the left view of figure 9. The mating face of the wear plate is illustrated in the right view of figure 9 and displayed a matching imprint of the gasket, indicated by the red arrows, consistent with a good all-round contact. The circle indicated by the black arrow is an imprint of the inner diameter of the gasket, and the blue arrows indicate discoloration on the wear plate surface located inside of that circle.

The impeller was extracted from the pump housing and examined. The examination revealed that the impeller was a dark gray color and displayed two distinct types of wear at the tip of each lobe. A typical lobe is illustrated in figure 10 with yellow arrows indicating three narrow bands of wear at the tip of each lobe. The narrow bands are located where the lobe initially contacts the three fingers of the cam (the three fingers on one end of the cam are indicated by the blue arrow in figure 12 and allow the entry and exit of water for the pumping action previously described). The four red arrows indicate wear that was deeper adjacent to the cam finger contact locations and tapered off as the distance from those locations increased.

Examination of the impeller cavity in the pump housing revealed small slivers of a dark gray material trapped between the cam and the cavity surfaces. Manipulation of larger slivers revealed that the dark gray material was flexible, consistent with it being impeller material. The flat face in the cavity displayed a discolored surface similar in appearance to that illustrated in the right view of figure 8 but was more of a dark blue. The surface displayed light circumferential rubbing marks with more faint imprints of the impeller

lobes than the impeller had lobes. The surface normally contacted by the impeller lobes displayed an imprint that matched the wear pattern on the lobes. Small particles of the dark gray material were observed on all surfaces contacted by the impeller lobes.

Manipulation of the impeller shaft revealed negligible lateral movement or end float and that it rotated smoothly and easily.

The shoulder on the forward face of the adapter plate is illustrated in figure 1 and locates the plate on the engine. The adapter plate is normally secured to the engine by two bolts with heads consisting of a hexagonal portion and a round portion. As illustrated in figure 2, the upper bolt appeared to be in contact with the adapter plate and the lower bolt, indicated by the blue arrow, appeared to be loose. Examination of the bolt holes in the adapter plate revealed contact marks on both. The upper and lower bolt holes are illustrated in the left and right views of figure 11 respectively, with a red arrow indicating the outer diameter of the washer portion of the bolt head and a yellow arrow indicating contact by the radius located between the washer portion of the head and the shank of the bolt.

Examination of the gear revealed a light wear pattern on each gear tooth contact flank consistent with what is accepted as normal engagement.

Exemplar pump examination.

The exemplar (test) pump was disassembled and is illustrated in figure 12 with the major components identified (the housing bolts were already loose following the testing). The housing bolts were also identified by their clock position as seen from the front of the engine.

The lock washer contact faces on the housing bolts are illustrated in figure 13 with red arrows indicating small rolls of material on the contact faces of the 3:00 and 11:00 bolts and the yellow arrow indicating a more distinct roll of material on the contact face of the 7:00 bolt. Plating had been removed from all three of the lock washer contact faces and displayed a circumferential orientation consistent with the sliding action of a contact face on a lock washer during a tightening operation. The lock washer contact face on the identification tag is also illustrated in figure 13 with the blue arrow indicating an indentation, similar to that on the identification tag on the accident pump and consistent with contact by the sharp edge of the lock washer during a loosening operation.

Examination of the lock washer contact face at the 3:00 location on the bearing housing revealed flattening of prominent surface dimples and a white metal deposited in isolated recesses, consistent with it being the location of the identification tag. The contact face at the 7:00 location displayed the flattening of prominent surface dimples, circumferential scratches and an indentation that would match the edge of the lock washer. The lock washer contact face at the 11:00 location is illustrated in the left view of figure 14 and displayed flattening of prominent surface dimples, indicated by the yellow arrows, circumferential scratches, indicated by the green arrows, multiple indications of indentations produced by the sharp edge of the lock washer, indicated by the red arrows.

All the features were located in a slight depression, where material had been removed, leaving the raised lip located between the two white arrows.

The pump housing was examined and, as illustrated in figure 12, was found to display negligible signs of usage. The o-ring was extracted from the pump housing and examined. The examination found it to be intact, with no tears, cuts or missing material, and that it had retained its round cross section.

The impeller side of the wear plate displayed a well defined imprint of the o-ring, indicated by the black arrow in figure 12, and the other side displayed a well defined imprint of the gasket. The impeller side also displayed a dark discoloration and light circumferential marks, indicated by the green arrow in figure 12, consistent with contact by the impeller and a relatively unmarked area, indicated by the white arrow in figure 12, that matched the profile of the cam. A closer examination of the discoloration revealed that it consisted of particles of a similar color as the impeller and manipulation of larger particles revealed that they were elastomeric.

Examination of the impeller revealed that it consisted of a black elastomeric material and displayed indentations and wear at the tip of each lobe, consistent with contact with the cam fingers. The yellow arrows in the right view of figure 14 indicate indentations from the edges of the fingers of the cam. The red arrows indicate areas of wear that correspond to the body of the cam contacted by the impeller after it had traversed the fingers.

Manipulation of the impeller shaft revealed negligible lateral movement or end float and that it rotated smoothly and easily.

Examination of the gear revealed a very light wear pattern on each gear tooth contact flank, consistent with normal contact over the pump's limited operating time.

Previous pump examination.

The previous pump was received with the pump housing attached to the bearing housing by electrical tape. The adapter plate was still bolted to the bearing housing but there were no housing bolts or a wear plate. The tape was cut and the housings separated. The separated housings are illustrated in figure 15 with the major components identified.

Examination of the three bolt holes in the bearing housing revealed a circular depression around each hole with circumferential scratches on its flat bottom surface, consistent with being worn by repeated applications of the housing bolts and spring washers. A typical bolt hole is illustrated in figure 16 with red arrows indicating the depression and yellow arrows indicating more prominent circumferential scratches. The diameter of the depression approximated that of the helical spring washers previously removed from the other pumps.

The impeller was extracted from the pump housing and an examination of the impeller cavity in the pump housing revealed a uniformly dull brown surface, similar to the color on the side of the cam and indicated by the blue arrow in figure 15. The flat surface did display light circumferential marks indicative of contact by a rotating impeller and imprints of impeller lobes. The impeller was a dark blue color and displayed light score marks consistent with it contacting the edges of the cam fingers. A portion of a typical impeller lobe is illustrated in figure 17 with yellow arrows indicating the light score marks and a red arrow indicating where a small piece was missing from the tip of the illustrated lobe.

The o-ring was extracted from the pump housing, and an examination revealed that it had a square cross section with small radii at the corners, consistent with it being compressed in its rectangular groove for a significant time. At one location a portion of an outer edge had been flattened and extruded outwards by compression between the wear plate and the pump housing.

The impeller shaft rotated easily but hesitantly, and the bearings emitted a rumbling noise, consistent with them being worn and dry. Manipulation of the shaft revealed significant lateral and longitudinal movement, also consistent with the bearings being worn. The worn bearings would be sufficient to make the seal ineffective and the subsequent leaking was probably the reason why it was replaced. Examination into the drip holes in the bearing housing revealed a thin metallic disc that moved freely in the gap between the bearings and was probably a loose bearing shield. Significant wear was observed on the impeller key, its slot in the impeller shaft and its keyway in the impeller's metal core. The end of the impeller shaft at the gear displayed a deformed center consistent with the use of a puller to remove the gear, indicating that the gear had been replaced or that this pump had been overhauled at some time.

Significant circumferential scoring was observed around the adapter plate bolt holes, consistent with repeated bolt tightening actions. The scoring around one bolt hole is indicated by the green arrow in figure 15.

Examination of the gear revealed a light polishing of almost the whole contact flank. Longitudinal movement of the shaft produced a gap of 0.1 inch between the gear and the adapter plate and allowed the gear to contact and score the adapter plate. The normally exposed surface of the adapter plate displayed dimples of various depths and sizes, consistent with corrosion, which had been cleaned and painted over. A majority of the smaller dimples were located around the two attachment holes.

Derek Nash
Mechanical Engineer

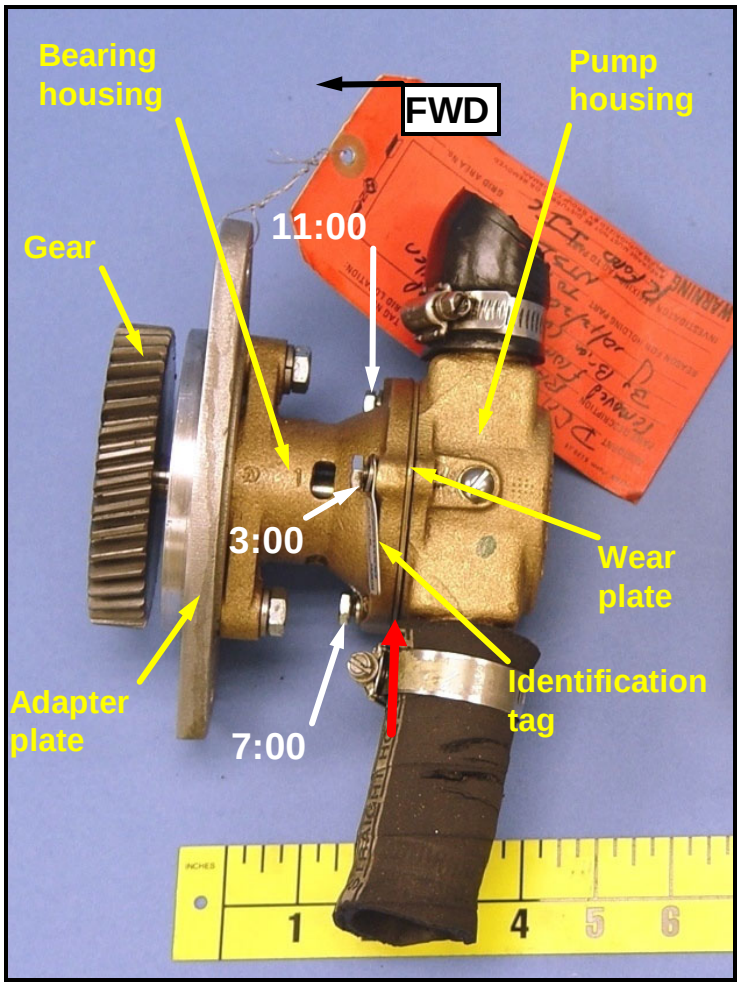

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Figure 1. The accident raw water pump received for examination.

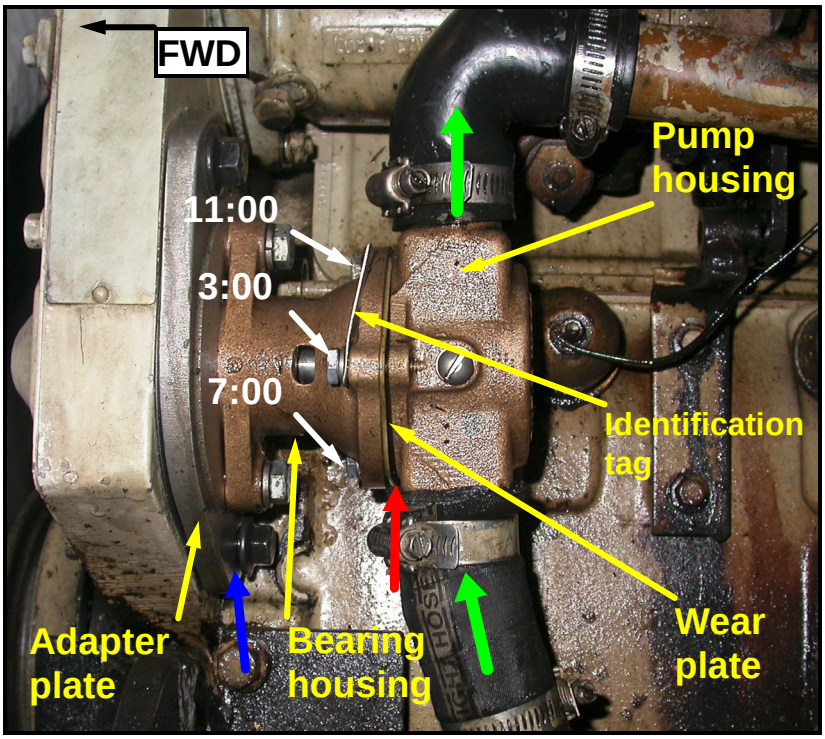

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Figure 2. On scene view of the accident pump attached to the engine.

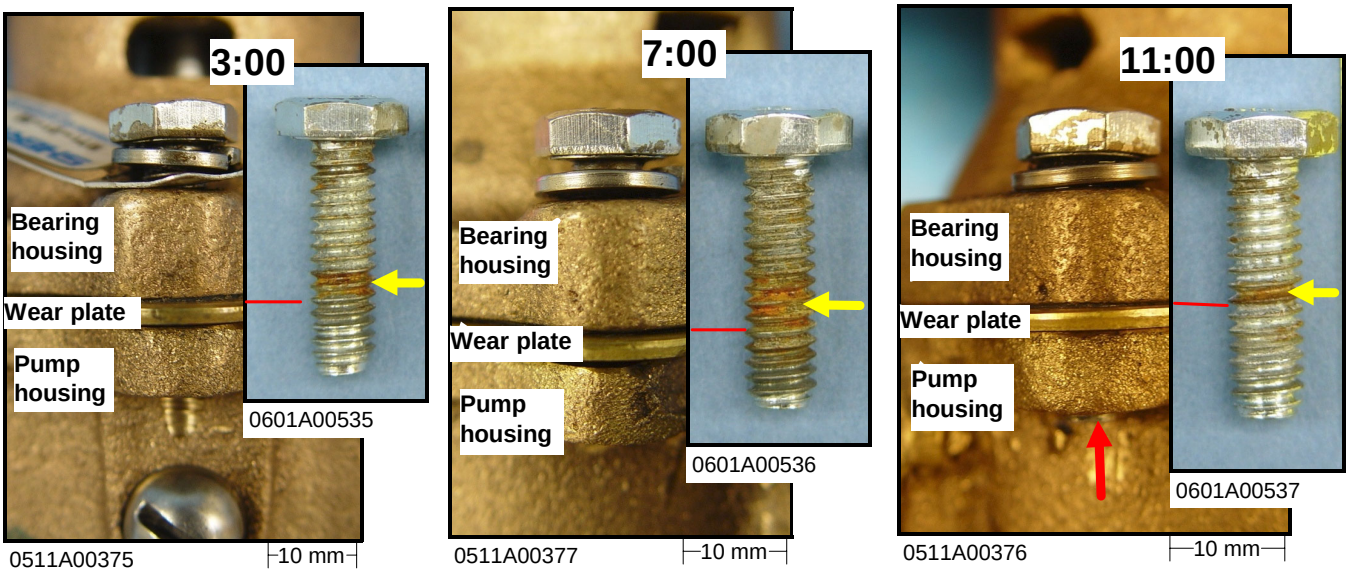


Figure 3. The 3:00, 7:00 and 11:00 housing bolts on the accident pump, as received, with an insert of the bolts (after removal) at a similar magnification.

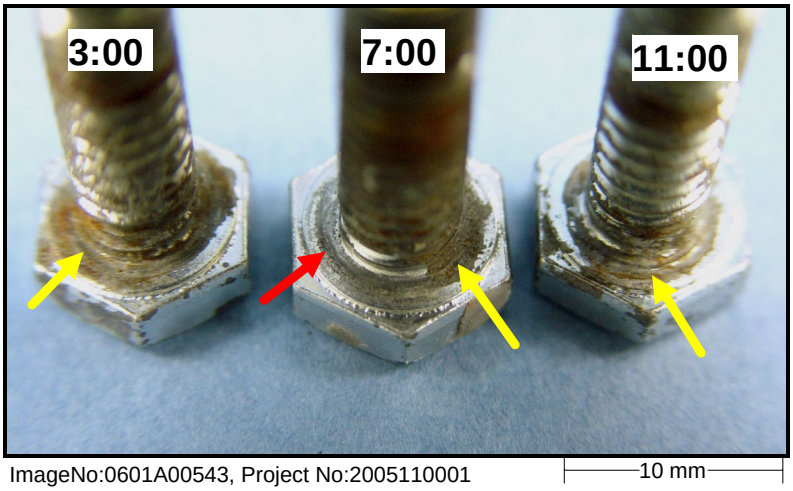


Figure 4. The lock washer contact faces on the accident pump housing bolts.

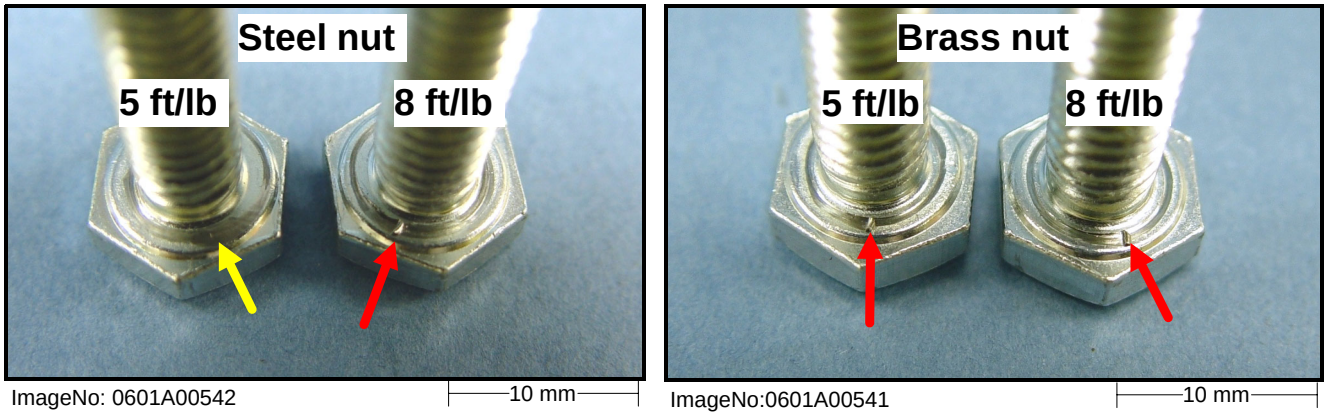
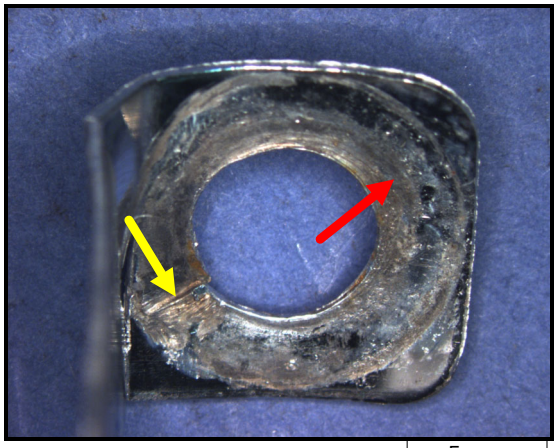
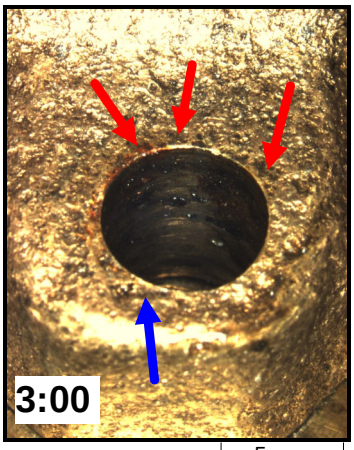


Figure 5. The lock washer contact faces on the exemplar bolts torqued into a steel nut (left) and into a brass nut (right) at the torque values indicated.



ImageNo: 0601A00151 5 mm

Figure 6. The lock washer contact face on the identification tag at the 3:00 housing bolt (left) and the contact face on the bearing housing below the tag (right).



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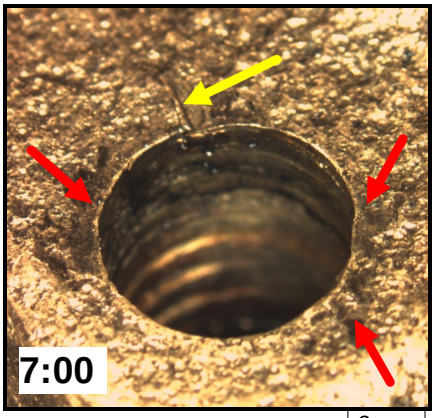

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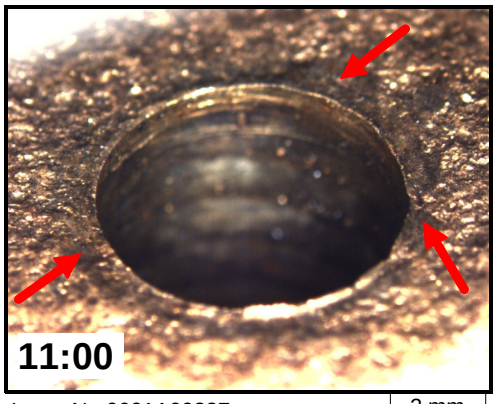
Figure 7. The bearing housing contact faces for the 7:00 lock washer (left) and for the 11:00 lock washer (right).



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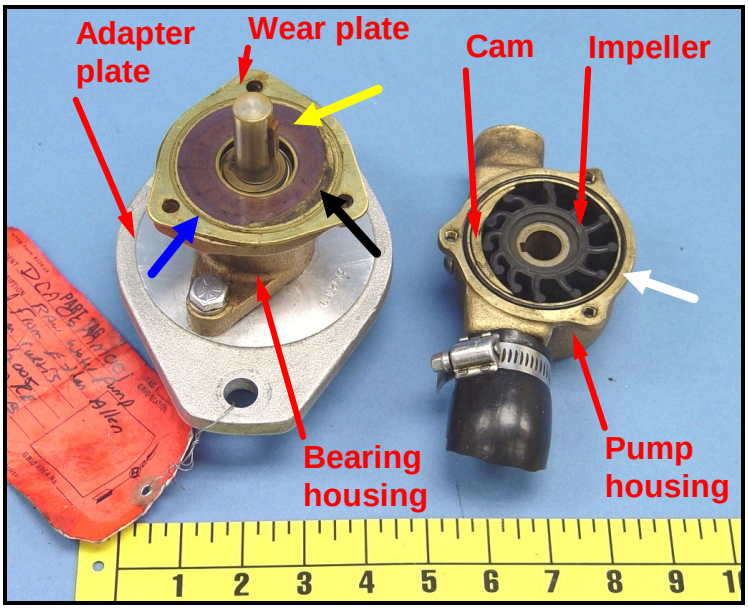

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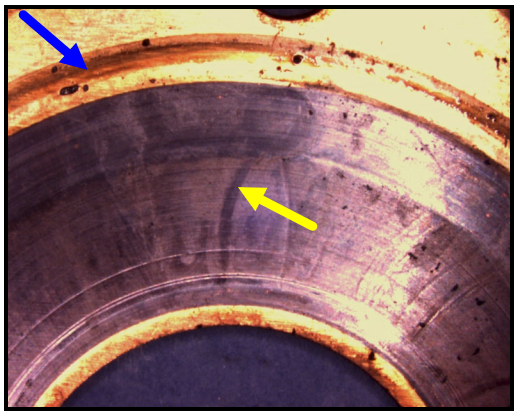

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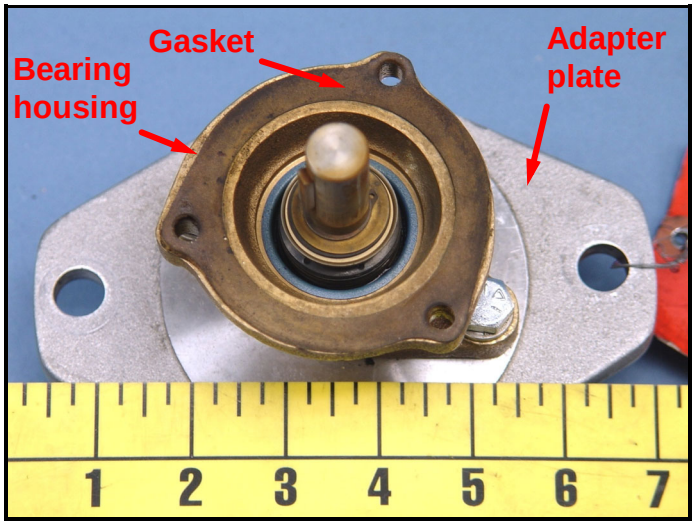
Figure 8. The accident pump partially disassembled (left) and a closer view of the discolored impeller contact face on the wear plate (right).



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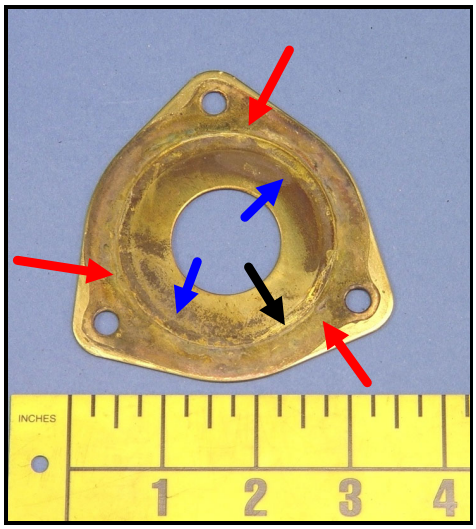

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Figure 9. The gasket between the bearing housing and the wear plate (left) and the impression it left on the wear plate (right).

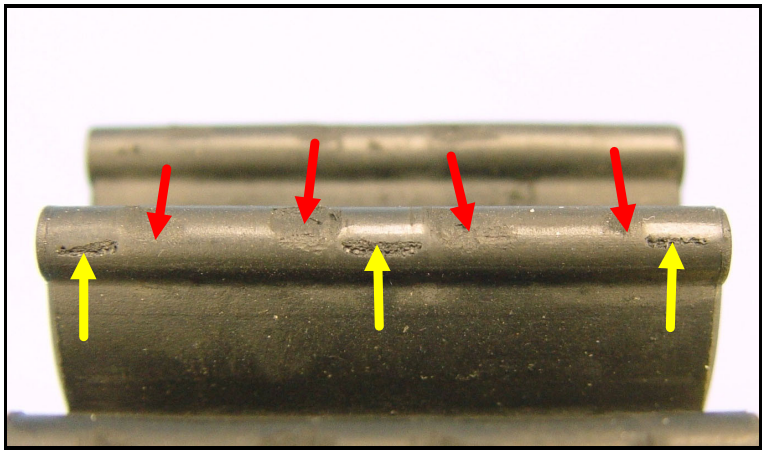

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Figure 10. Typical wear patterns on one lobe of the accident pump impeller.

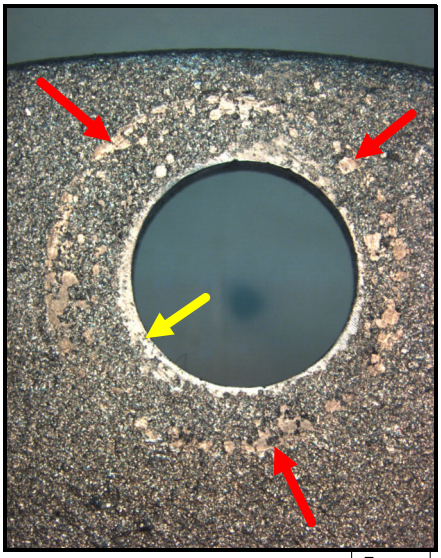

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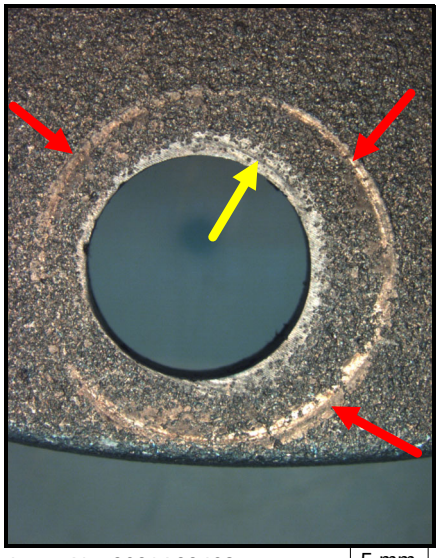
Figure 11. Contact marks on the upper (left) and lower (right) mounting holes of the accident pump adapter plate.



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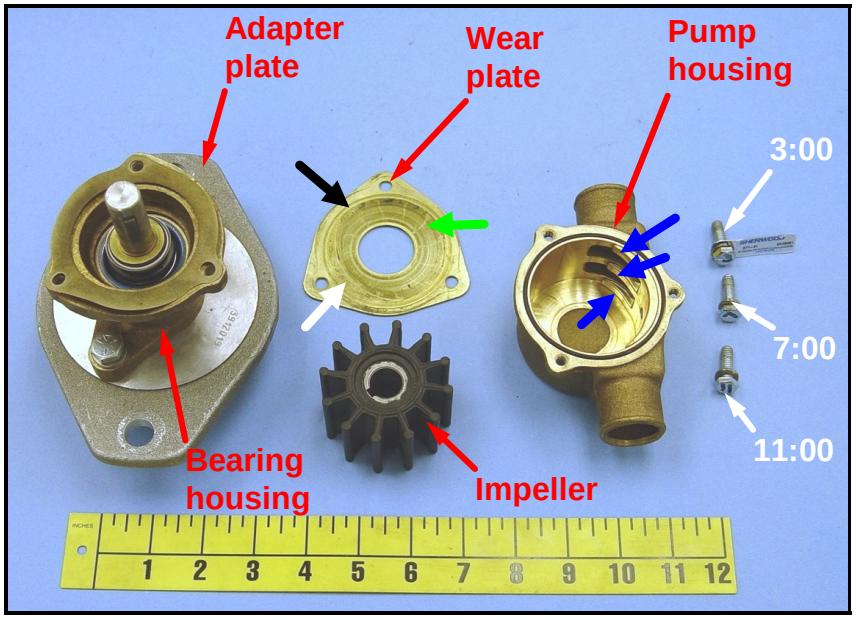

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Figure 12. The partially disassembled test pump.

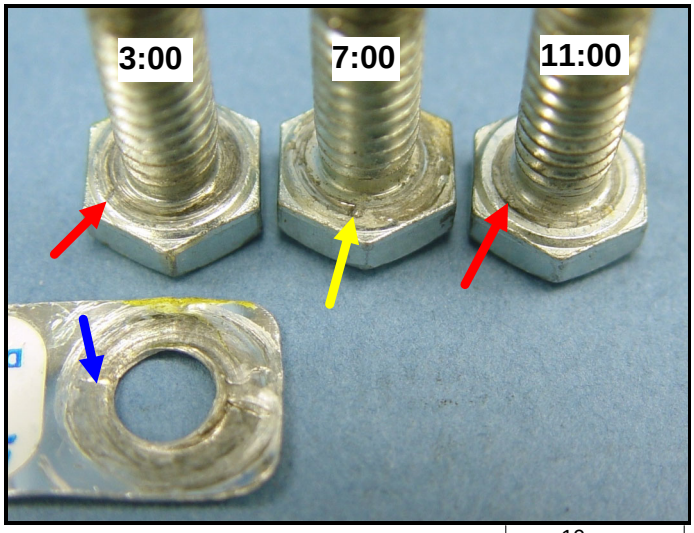

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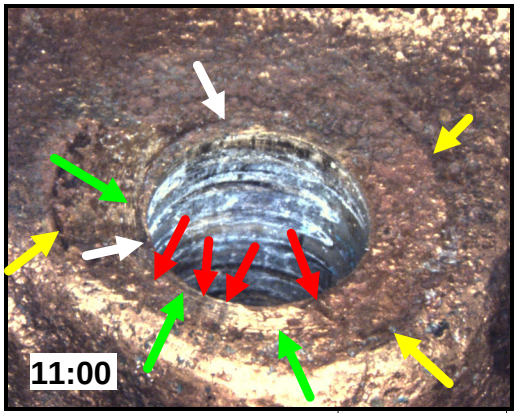
Figure 13. The lock washer contact faces on the test pump housing bolts with their clock position indicated.



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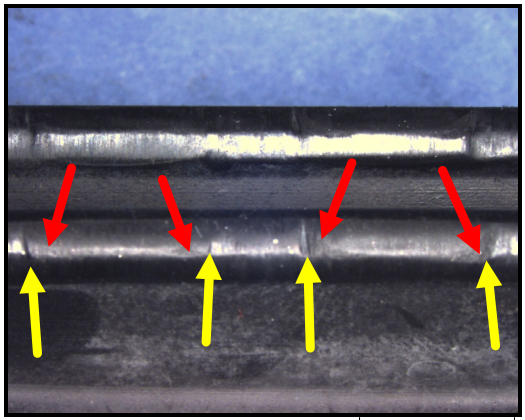

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Figure 14. Lock washer contact face at the 11:00 position on the test pump bearing housing (left) and typical wear on a lobe of the test pump impeller (right).

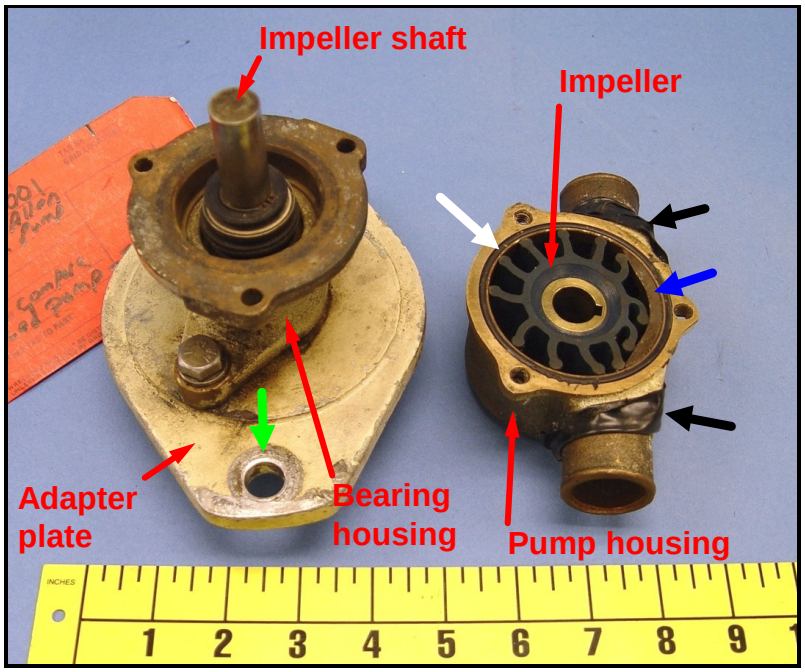

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Figure 15. The previous pump components received for examination, with the pump housing separated from the bearing housing.

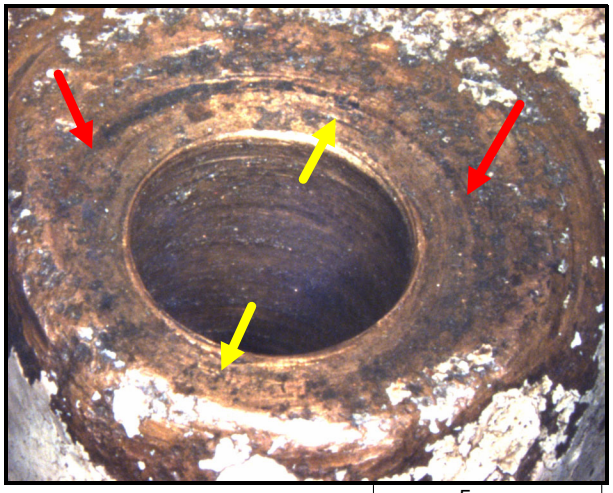

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Figure 16. Typical features on a lock washer contact face on the bearing housing of the previous pump.

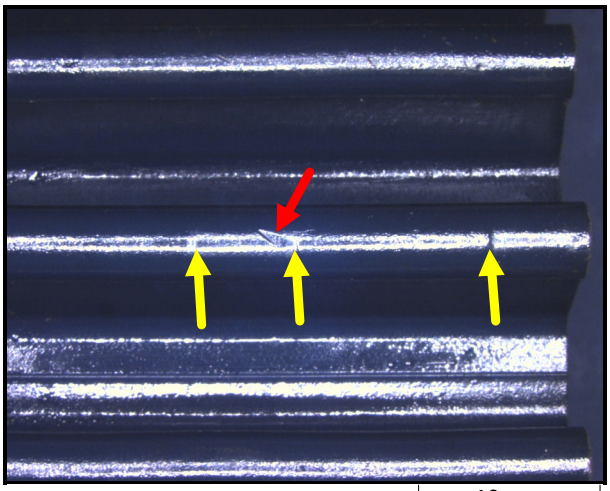

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Figure 17. Typical wear marks on one lobe of the the impeller in the previous pump.